CHARACTERIZATION OF CORNCOB ASH (CCA) AS A POZZOLANIC MATERIAL

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ABSTRACT

Disparity in the Characterization of corncob ash (CCA) as a pozzolanic material and scant literature pertaining to its microstructural characteristics motivated the objective of this research. The study intends to narrow the knowledge gap by examining the physical and chemical properties, microstructural characteristics of CCA and the 28-days compressive strength of 100 × 200 mm cylindrical hardened concrete specimen; for the assessment of its strength activity index (SAI). The CCA examined had specific gravity of 3.49; with chemical compositions, which classified it as class C Pozzolan. The micrograph image showed some polygonal-shaped particles with a wide particle size distribution and agglomeration of its particles, while the SAI of the hardened concrete specimens examined was 92%. The study revealed that the source and processing methods of CCA influences its Characterization. SAI does not adequately indicate pozzolanic properties and reduced compressive strengths of CCA blended concrete may be attributed to the possible agglomeration of CCA in hardened concretes.
Keywords: corncob ash; pozzolan; pozzolanic activity; strength activity index; supplementary cementitious materials.


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1. INTRODUCTION

Civil engineering practices and construction works around the world depend to a very large extent on concrete (Olafusi et al., 2017). Meanwhile, scholarly reports on the use of agro-wastes and supplementary cementitious materials (SCM) such as Pozzolan in concrete production have vastly impacted the rheology, strength and durability properties of concretes; while also mitigating the challenges of solid waste management (Aulakhet et al., 2018; Olafusi et al. 2017; Kamau et al. 2017; Kamau et al. 2016; Olusola and Joshua, 2012). Additionally, concrete made from Pozzolan blended cement is reported to be more durable even in harsher service environments such as in phosphate and sulphate environments (Olusola and Joshua, 2012).

The recycling of agro-wastes and other SCM for use in concrete production and other construction materials, have gained impressive scholarly research coverage, owing to the increasing environmental issues arising from the emission of CO$_2$ during the production of cement. Over 5% of CO$_2$ global emissions occur in concrete production with the manufacture of cement being the major contributing factor (Rao et al., 2014; Johnson and Gonzalez, 2013; Gambhir, 2009; Crow, 2008; Mehta, 2001). Nigeria is Sub-Saharan Africa’s largest cement producer, while South Africa is the second largest cement producer in Africa. Together they contribute over 29 and 17.5 million tons respectively, to the annual 2.8 billion tons of global cement production (Mapiravana, 2009; Nigerian Cement Industry, 2014).

The high cost of housing and infrastructural development is also attributed largely to the use of cement and concrete, which is the most influential material in the construction industry, since cement is the most utilized material globally, and its consumption only seconds that of water (Islam and Islam, 2013).

Despite the significant research outcomes on the use of agro-wastes and SCM in concrete production, some of the limitations of the reports is as a result of insufficient information on the microstructural characteristics and the Characterization of the Pozzolan that influences the pozzolanic reactivity. Similarly, there have been some research outcomes on the use of CCA as a pozzolanic material, but not much has been produced on its microstructural characteristics, nor its Characterization and strength activity index (SAI) as it relates to its pozzolanic potentials. Some research outcomes that are inclined to investigate the characteristics of CCA as a Pozzolan includes, the effects of heat treatment on chemical composition, physical properties and engineering properties of corncob ash by Suwanmaneechot et al. (2015); where it was reported that X-ray diffraction patterns revealed an increased amorphous silica phase with increasing calcining temperatures, and the composition of SiO$_2$, Al$_2$O$_3$ and Fe$_2$O$_3$ tend to increase with increments in the calcined temperature. Raheem et al. (2010), in their study on the effect of admixtures on the properties of CCA cement concrete; reported on the workability and compressive strength of CCA cement concrete incorporated with accelerator, plasticizer and water reducing admixtures. Wardhani et al. (2017), studied the method to obtain silica from corncob ash using thermal and non-thermal methods. Other studies such as (Kamau et al.
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2017; Kamau and Ahmed, 2017; Olafusi et al., 2017; Kamau et al., 2016a; Kamau et al., 2016b; Olafusi and Olutoge, 2012; Adesanya and Raheem, 2008; Udoeyo and Abubakar, 2003), investigated and reported on the influence of CCA on the rheology, strength and durability properties of CCA in concretes.

This paper however focuses on the Characterization of CCA (generated from corncob agro-waste as a pozzolanic material in concrete production), its microstructural properties and its strength activity index as it affects its pozzolanic activity.

2. MATERIALS AND METHODS

2.1. Materials

Corncobs used in this research were sourced from Sagamu, Ogun State, Nigeria. The corncobs were air-dried in the sun to reduce its moisture content, and were pulverized using a milling machine to reduce the average grain size of the cobs. Subsequently, the pulverized corncobs were taken into a ‘muffle carbolite furnace’ in batches for incineration. The pulverized corncobs were placed on a porcelain crucible and then placed inside the muffle carbolite furnace, while the temperature of the furnace was maintained between 625-650°C for about 4-5 hours per batch to complete the removal of the carbonaceous material until white ash residue was noticed. According to Suwanmaneechot et al. (2015), CCA exhibits more appropriate behaviors of pozzolanic material when calcined at 600°C temperature.

2.2. Properties and Characterization of CCA

The physical properties of CCA, which included its particle size analysis, bulk density, specific gravity and its chemical properties were examined and reported.

The CCA was also used as a cement blend of 0-20% in a concrete mix designed with CCA in steps of 5%, to examine the influence of the CCA on the 28-day compressive strength of hardened concrete and its strength activity index (SAI). SAI according to Joshua et al. (2018) is the ratio of the 28-day strengths at 20% cement replacement with a Pozzolan and the control (0% replacement). 0% CCA blended cement served specimen as the reference specimen with no CCA content, while the 5%, 10%, 15% and 20% CCA blended cement specimens had cement replaced by CCA in 5, 10, 15 and 20% by weight respectively. Thirty (30) cylindrical concrete specimens of 100 mm diameter × 200 mm length were used for the hardened concrete sampling. The fresh concrete specimens were left in the cylindrical molds for 24 hours before being demoulded and subsequently cured by full immersion in curing tanks until the 7 and 28-days compressive strength examined according to standard testing procedures (ASTM, 2005). The reported results of the compressive strength examinations, were the average of three test results.

The microstructural characteristics of the CCA was examined by an AURIGA scanning electron microscope (SEM) by ‘Carl Zeiss Germany’ with an accelerating voltage of 15 kV. Sample specimens were gold coated in a gold sputter coater for 90 seconds at 15 mA current output. The gold coating was necessary to ensure a conducting surface was obtained for electron bombardment and Characterization. The selected areas of interest were focused and micrographs were taken. With an accelerating voltage of 15 kV.
3. RESULTS AND DISCUSSION

3.1. Physical Properties of CCA

The physical properties examination revealed a grayish purple colored CCA with an average particle size of 75 µm and specific gravity of 3.49 as presented in Table 1. The calcination of 120.33 kg of corncobs, generated 1.48 kg of CCA; which implies an ash to solid ratio of 0.012. The fineness of the CCA used for the research was the same as that for cement, as it relatively influences hydration rate and strength gain in concrete (Kosmatka et al., 2002). They further opined that the smaller the particle size, the greater the surface area-to-volume ratio, and thus, the more area available for water-cement interaction per unit volume. The effects of greater fineness on strength is seen during the first seven days. According to Aulakhet et al. (2018), the main binding component of cement is calcium oxide (CaO) and similar to their report on the chemical properties of rice husk ash (RHA); and those of (Kamau et al., 2016b; Suwanmaneechot et al., 2015; Adesanya and Raheem, 2008; Udoeyo and Abubakar, 2003) on the chemical properties of CCA, CaO had a lower percentage composition in CCA compared to cement; but confirms its potential for a fractional replacement for cement in concrete. Although, Hannesson et al. (2012) confirmed that pozzolans are characterized by a delayed strength gain because they contain lower levels of CaO which is essential for early strength development. Pozzolans therefore only act as fillers in the early curing age of concretes without contributing to strength, as they have to allow for the hydration products of cement, such as calcium hydroxide [Ca(OH)2], with which they react at a latter curing age to form further strength giving compounds such as Calcium Silicate Hydrate (C-S-H) (Bapat, 2012). This reaction of Pozzolans with Ca(OH)2 is known as the pozzolanic reaction and is shown in equations 2 (Suwanmaneechot et al., 2015). The formation of C-S-H slows down ingress of aggressive substances, thus enhancing the durability properties of hardened concrete in resisting chemical attack (Kamau and Ahmed, 2017).

C3S (OPC) + C2S (OPC) + H2O → C-S-H + Ca(OH)2 \hspace{1cm} (1)
SiO2 (CCA) + Ca(OH)2 + nH2O → C-S-H + SiO2 (unreacted) \hspace{1cm} (2)

<table>
<thead>
<tr>
<th></th>
<th>Particle Size (µm)</th>
<th>Specific gravity</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>75</td>
<td>3.15</td>
<td>Grey</td>
</tr>
<tr>
<td>CCA</td>
<td>75</td>
<td>3.49</td>
<td>Greyish Purple</td>
</tr>
</tbody>
</table>

3.2. Chemical Properties of CCA

The result of the chemical composition presented in Table 2 indicated that CCA is a class C Pozzolan, with an aggregated sum of silicon dioxide (SiO2), aluminum oxide (Al2O3) and Ferric oxide (Fe2O3) at 64.58%, which is higher than the required 50% specified by ASTM (2015); where a Pozzolan is classified as Class C pozzolanic material, when the sum of the composition SiO2, Al2O3 and Fe2O3 in the ash exceeds 50% and class N when their composition exceeds 70%. The result confirms pozzolanic activity in CCA despite the non-detection of Fe2O3; which basically provides color and hardness in cement. Although, it also provides some strength, the major function of SiO2 which is the dominant composition of the CCA with 59.66% composition as presented in Table 1; predominantly compliments CaO to impart strength in cements. Al2O3 with 4.92% composition influences the increased setting property of cement. The Variations in chemical constituents however affect the hardening, setting time, color and corrosion resistance properties of cement and SCM (El-gray et al. 2016 and Neville, 1996).
Table 2. Chemical properties of CCA and Cement

<table>
<thead>
<tr>
<th>Chemical Composition (%)</th>
<th>Al₂O₃</th>
<th>SiO₂</th>
<th>Fe₂O₃</th>
<th>CaO</th>
<th>MgO</th>
<th>K₂O</th>
<th>Na₂O</th>
<th>Mn₂O₃</th>
<th>SiO₂ + Al₂O₃ + Fe₂O₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>4.42</td>
<td>17.45</td>
<td>3.93</td>
<td>65.84</td>
<td>2.35</td>
<td>1.12</td>
<td>0.25</td>
<td>0.06</td>
<td>-</td>
</tr>
<tr>
<td>CCA</td>
<td>4.92</td>
<td>59.66</td>
<td>ND</td>
<td>1.86</td>
<td>1.68</td>
<td>15.48</td>
<td>0.34</td>
<td>0.01</td>
<td>64.58</td>
</tr>
</tbody>
</table>

Kamau et al. (2016b), in their research on the suitability of CCA as a SCM; reported the sum of the composition of SiO₂, Al₂O₃ and Fe₂O₃ in CCA as 54.1%, which aligns with the classification of CCA as a Class C pozzolan as reported in this study. Adesanya and Raheem (2008) and Udoeyo and Abubakar (2003) reported that the sum of the composition of SiO₂, Al₂O₃ and Fe₂O₃ was in the excess of 70%; which classified CCA as a Class N pozzolanic material according to ASTM (2015). The variation in the reported chemical compositions could be attributed to the source of the pulverized corncobs and ashing methods employed by the various scholars. The sourcing and ashing methods for Adesanya and Raheem (2008) and Udoeyo and Abubakar (2003) were similar compared to Kamau et al. (2016b). Furthermore, Suwanmaneecho et al. (2015) reported an increase in the composition of SiO₂, Al₂O₃ and Fe₂O₃ in CCA from an initial 68.11% to 71.87%; which they attributed to the vaporization of some elements such as carbon, calcium or magnesium during heat treatment. The reported results of (Kamau et al., 2016b; Suwanmaneecho et al., 2015; Adesanya and Raheem, 2008; Udoeyo and Abubakar, 2003), aligned with the outcome of this research study to confirm pozzolanic activity in CCA; but differed in its classification. Hence, this confirms the influence of sourcing and ashing methods on the classification of CCA.

3.3. Compressive Strength of CCA Blended Cement Concrete

Figure 1 showed that the SAI was 92%; and pozzolanic activity is said to be hypothesized when SAI is equal to or greater than 75% (ASTM, 2015). This research study revealed that the SAI of CCA is of great concern, as the review of the compressive strengths reported by (Kamau et al., 2016b; Adesanya and Raheem, 2008; Udoeyo and Abubakar, 2003) were below the recommended 75%. However, if SAI is a function of the compressive strength characteristics of hardened concrete, it is logical to examine the other factors such as the mix proportions, water-cement ratio, aggregate properties and curing method that influence the strength of hardened concrete. There is a possibility that relative mix designs, compaction and curing methods for cement concretes may not apply to CCA blended concretes or concretes containing CCA. This is because, despite the low SAI reported by (Kamau et al., 2016b; Adesanya and Raheem, 2008; Udoeyo and Abubakar, 2003), pozzolanic activity was confirmed by scholars; as the pozzolan influenced workability, compressive strength and durability performances of the concretes investigated.

The SAI reported by (Kamau and Ahmed, 2017; Kamau et al., 2016b; Adesanya and Raheem, 2008) could be attributed to the findings of (Olafusi et al., 2017; Hannesson et al., 2012; Olafusi and Olutoge, 2012; Raheem et al., 2010); that indicates pozzolanic activity extends beyond 28-day compressive strength properties for SCM blended concretes, as they tend to develop higher strengths beyond 28 days compared to those of 100% cement. However, further research is recommended on the inference of SAI on the pozzolanic characteristics of CCA.
3.4. Morphology of CCA

The morphology of CCA observed by the SEM micrograph as shown in Figure 2, indicated that CCA exhibits a polygonal shape, a wide range of particle size distribution and agglomeration of some particles. The micrograph corresponds to those reported by (Suwanmaneechot et al., 2015), and implies a possible agglomeration of the CCA in the hardened concrete composites examined. Additionally, this confirms the opinion of Mehta (1981); that the morphology of pozzolans affects the rate of pozzolanic reaction and the reduced compressive strengths of Pozzolan blended cement concretes at higher weight replacements, as reported in this study and those of (Olafusi et al., 2017; Kamau and Ahmed, 2017; Kamau et al., 2016a; Kamau et al., 2016b; Olafusi and Olutoge, 2012; Raheem et al., 2010; Adesanya and Raheem, 2008; Udoeyo and Abubakar, 2003). Thermal activation has been reported to enhance pozzolanic reaction and the compressive strength of Pozzolan blended cement concretes; by significantly increasing the surface area or partial aggregation of the smallest particles of the activated Pozzolan (Illic et al., 2016; Fabri, et al., 2013; Saleh, 2012).
4. CONCLUSION

The following conclusions were inferred from the studies:

CCA undoubtedly possesses pozzolanic attributes and can partially replace cement in concretes, subject to the target compressive strength requirement and its intended structural purpose.

CCA could be classified either as a class ‘C’ or ‘N’ pozzolanic material, which is dependent on the source of the corncobs, the ashing method and thermal activation employed for the CCA.

The inference of strength activity index on the pozzolanic characteristics of CCA is disputable, as it does not adequately indicate the pozzolanic properties of CCA.

Reduced compressive strengths of CCA blended cement hardened concretes with increasing weight replacements may be attributed to the agglomeration of CCA in hardened concrete composites, and may be enhanced by thermal activity of the Pozzolan.

RECOMMENDATION

Further research is recommended on the inference of strength activity index on the pozzolanic characteristics of corncob ash and a detailed mapping of the Characterization of CCA based on different sources, processing methods and thermal activation.

REFERENCES


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